Developmental Thresholds and Degree-Day Accumulations of Indianmeal Moth (Lepidoptera: Pyralidae) on Dried Fruits and Nuts

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ABSTRACT Degree-days for egg to adult development were determined for a laboratory and a wild-type isolate of the Indianmeal moth, *Plodia interpunctella* (Hübner), reared on wheat bran diet, almonds, pistachios, walnuts, raisins, and prunes. To avoid problems with temperature-induced diapause and effects of diet, eggs and pupae were used to estimate developmental thresholds used in degree-day determinations. Lower developmental thresholds for eggs (14.8°C) and pupae (13.8°C) of both isolates were identical. A threshold of 14°C was used for degree-day determinations for both isolates. Egg hatch on all diets was lower for the wild-type isolate, but postembryonic survival of the wild-type isolate was similar to the laboratory isolate. Survival was <12% on dried fruits, 76.5–91.7% on nuts, and 95.3–97.3% on wheat bran. Degree-days for the laboratory isolate for each diet was lower than those for the wild-type isolate. Degree-days for each isolate was lowest when reared on wheat bran and highest when reared on dried fruits. The determination of developmental thresholds for eggs and pupae allows the use of a single lower threshold for all models, although different degree-days will be necessary for each commodity.

KEY WORDS *Plodia interpunctella*, developmental rates, developmental thresholds

THE INDIANMEAL MOTH, *Plodia interpunctella* (Hübner), is a cosmopolitan pest that will develop on a variety of grains, nuts, beans, meals, dried fruits, and processed foods (Simmons & Nelson 1975). In California it is a major problem during processing and storage of dried fruit and nut commodities. Currently, control practices rely on scheduled fumigation with methyl bromide or hydrogen phosphide. Methyl bromide has recently been classified as an ozone depleter (EPA 1993), which will result in its use being severely restricted or eliminated. Insect resistance to hydrogen phosphine has been documented in other commodities (Zettler et al. 1989). Consequently, concern over the possible restriction of these fumigants has generated interest in reducing the number of fumigation treatments. One approach is to fumigate only when needed, but because of the lack of direct sampling methods for these commodities, it is difficult to determine when treatment is necessary. However, by combining commercially available pheromone lures with a phenological model, it would be possible to time fumigations for maximum efficacy.

Developmental rate, survival, and reproduction of Indianmeal moth is known to be affected by larval diet (Savov 1973a, LeCato 1976, Hoppe 1981, Cline & Highland 1985). Therefore, any model developed to predict phenology must take diet into account. Johnson et al (1992) studied development of Indianmeal moth at constant temperatures on wheat bran and ground almonds, walnuts, and pistachios to determine developmental thresholds, but was limited to temperatures of 22°C and above because lower temperatures induced diapause in fifth instars. One way to avoid this problem is to determine developmental thresholds for eggs or pupae alone. We report results of a study to determine degree-days for egg to adult development of two Indianmeal moth isolates on several diets, using developmental thresholds estimated for Indianmeal moth eggs and pupae. Comparisons of Indianmeal moth development on shelled almonds, walnuts, and pistachios, raisins and prunes, as well as on a standard wheat bran diet, were made.

Materials and Methods

Two Indianmeal moth isolates were used in the study. The laboratory isolate was obtained from a walnut packinghouse in Modesto, CA, in November

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1967. The wild-type isolate was obtained from a culled fig warehouse in Fresno, CA, in July 1990. Both isolates were maintained on a wheat bran diet modified from Finney & Brinkman (1967) (Tebbets et al. 1978). Normal rearing conditions were 28°C, 60% RH, and a photoperiod of 14:10 (L:D) h.

Developmental Thresholds. Developmental thresholds for eggs and pupae of both isolates were determined using temperatures of approximately 19, 22, 25, 28, 31, and 34 ± 0.5°C. Temperatures were maintained in environmental test chambers kept at 50% RH and a photoperiod of 14:10 (L:D) h. Actual average temperatures were measured with a Polycorder datalogger (Omnidata, Logan, UT) and type T thermocouples made from 36-gauge wire.

Indianmeal moth eggs were collected for 4 h (from 0900 to 1300 hours PST) from oviposition jars containing 100–150 adults. Scales were removed from eggs by gently shaking the collection container under a fume hood. The eggs were then passed through a 32-mesh brass screen to remove clumps of eggs and moth body parts. Eggs were placed in cups made from hollow plastic test tube caps (13 by 4 mm). The bottoms of the caps were cut off, and 100-mesh brass screen was heat-sealed to the cut edges. A balance was used to weigh out 2.1 mg of eggs (≈100 eggs) into each cup, which was placed in a 55-mm-diameter glass petri dish bottom containing 2.5 g of wheat bran diet. The dish was sealed in a 150-mm-diameter covered plastic petri dish along with another 55-mm-diameter glass dish containing 22 mm of glycerine solution adjusted to maintain 60% RH (Braun & Braun 1958). A thermocouple was taped inside each plastic dish and the dish was placed on the stage of a dissecting microscope located inside each test chamber, so egg hatch could be counted in place. Eggs were checked for hatching every 6 h. Once hatching began, hatched eggs were counted every other hour.

Indianmeal moth prepupae were collected in 3-cm sections of plastic cocktail straws twice daily from rearing jars. The straws were examined with a light board every 6 h to remove new pupae. For each temperature, four 100-mm-diameter plastic petri dishes lined with filter paper with straws containing 25 pupae were placed in a plastic shoe box (25 by 36 cm). A dish containing 200 ml of glycerine adjusted to maintain 60% RH was added and a thermocouple was taped inside each of the boxes, which were then sealed with clear plastic food wrap and placed in the environmental chambers. The boxes were checked every 12 h for adult emergence. Once emergence began, adults were counted every 4 h.

For both eggs and pupae, the above design was replicated twice over time for the laboratory isolate, and once for the wild-type isolate. The average time in days from oviposition to egg hatch, or from pupal eclosion to adult emergence was calculated for each temperature as mean developmental duration. Developmental rate was expressed as the reciprocal of duration. Developmental rate was regressed against temperature and a lower developmental threshold estimated.

Degree-Day Determinations. The study was conducted in a small rearing room with ambient relative humidity and a photoperiod of 14:10 (L:D) h. Air conditioning and heating of the room was adjusted to allow temperatures to fluctuate between 15 and 35°C. The diets included in the test were wheat bran, 'Kerman' pistachio whole nutmeats, 'Nonpareil' almond whole nutmeats, 'Hartley' walnut half nutmeats, 'Thompson Seedless' raisins, and prunes. One kilogram of nuts or dried fruit, or 600 g of wheat bran diet was placed in 4-liter glass jars with screw top lids. A 65-mm-diameter hole was cut in each lid and covered with 40-mesh brass screen to provide ventilation. Five jars for each diet and isolate were used. A type T thermocouple was placed about 3 cm beneath the diet surface in one jar of each of the diets.

Eggs were collected over a 16-h period from oviposition jars set up in the rearing room. For each diet and isolate, three egg cups each containing ≈100 eggs (2.1 mg) were placed on the surface of the diet in four jars. Diet was infested with eggs from the laboratory isolate on 29 June 1990, and with eggs from the wild-type isolate on 31 July 1990. The fifth jar was left uninfested and the diet was used for moisture determinations. After egg hatch was complete (≈1 wk), the cups were removed and hatched and unhatched eggs were counted. Jars were monitored daily for adult emergence. Adults were collected from each of the jars, and their sex determined. Survival was calculated from hatched eggs.

Moisture content was estimated at the beginning and end of the developmental period for each diet and isolate. Moisture content was determined by toluene distillation for the wheat bran; moisture content of the nuts was determined in a vacuum oven (Horowitz 1980). When possible, moisture content of the raisins and prunes was determined with a dried fruit moisture tester (DFA type A Series, Horowitz 1980), otherwise a vacuum oven was used.

Using the average hourly temperatures for the test jars and the lower developmental threshold estimated earlier, average degree-days to adult emergence was calculated for each jar. SAS procedure GLM (SAS Institute 1987) was used to compute a two-way analysis of variance (ANOVA) to test for the effects of isolate and diet, and their interaction for egg hatch, survival, total emerged moths, and degree-days. Multiple comparisons among diets were computed within isolates using Tukey's studentized range test; and comparisons between the isolates were made with SAS procedure TTEST (SAS Institute 1987).

Effect of Diet on Reproduction. Moths in copulo were carefully collected from the diet jars and placed in 500-ml plastic containers containing 125

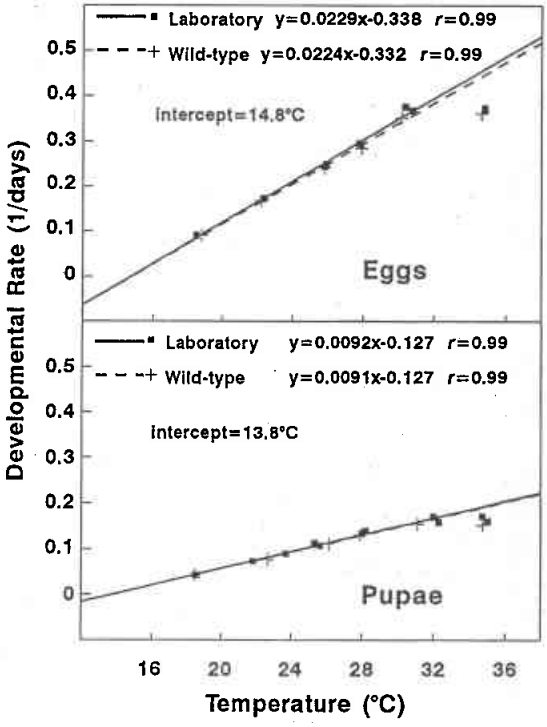

Fig. 1. Developmental rates of eggs and pupae from laboratory and wild-type Indianmeal moth isolates.

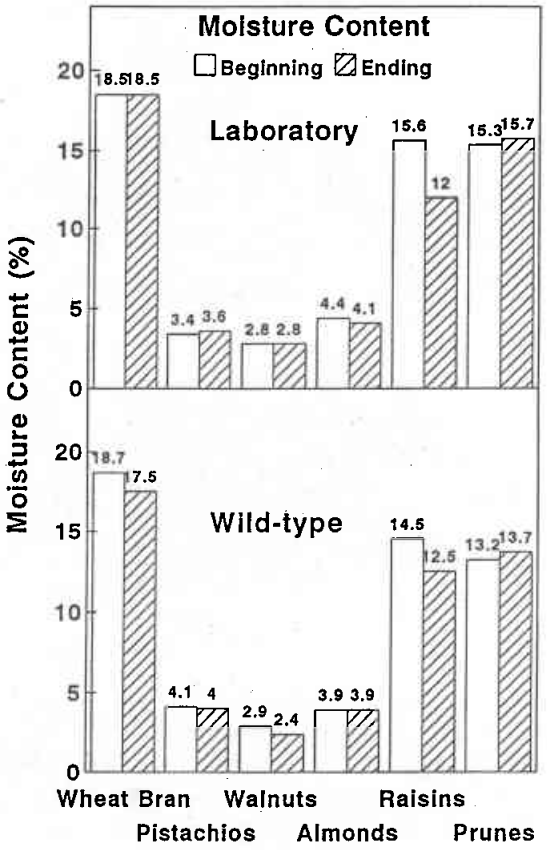

Fig. 2. Moisture contents of diets used in degree-day determinations.

g of wheat bran diet. When mating pairs were not available, calling females were matched with newly emerged males. Except for the laboratory isolate on prunes, at least 15 pairs were collected for each diet and isolate. Only six pairs of the laboratory isolate on prunes were recovered. The containers were kept in the rearing room. As adult progeny emerged they were collected daily and their sex determined. SAS procedure GLM (SAS Institute 1987) was used to compute a two-way ANOVA to test for the effects of isolate and diet, and their interaction for total progeny and progeny sex ratio. Multiple comparisons among diets were computed within isolates using Tukey's studentized range test; and comparisons between the isolates were made with SAS procedure TTEST (SAS Institute 1987).

Results

Developmental Thresholds. Developmental rates for eggs and pupae of both isolates were very similar (Fig. 1). Developmental rates increased linearly with temperature to 31°C; for both eggs and pupae developmental rates decreased slightly at temperatures of ≈34°C. For this reason, the highest temperatures (≈34°C) were not used in linear regression analysis. Correlations of developmental rates with temperature for eggs and pupae for both isolates were very high (r = 0.99). The lower developmental thresholds were calculated as 14.8°C for eggs and 13.8°C for pupae. It was decided to use a threshold of 14°C for future degree-day calculations.

Degree-Day Determinations. Beginning and ending moisture contents for the different diets are shown in Fig. 2. Moisture contents in the nuts and wheat bran diet did not change appreciably, although the wheat bran for the wild-type isolate did drop from 18.7 to 17.5%. The biggest change in moisture occurred in raisins for the laboratory isolate (from 15.6 to 12%). Also, both raisins and prunes for the wild-type isolate were drier than those used for the laboratory isolate. Because the diets were infested with the wild-type isolate a month after the laboratory isolate, the dried fruits were kept in storage, and may have lost moisture during this time.

Egg hatch and survival of the two isolates are shown in Table 1. We were unable to determine egg hatch for the laboratory isolate on wheat bran because developing larvae crawled back into the egg containers before counts could be made. Consequently, an overall average egg hatch for the laboratory isolate on all other diets was used to estimate survival for wheat bran. The value for egg hatch of wheat bran was excluded from statistical analysis.

Table 1. Egg hatch and survival of two Indianmeal moth isolates on different diets

Diet	Mean % egg hatch ± SEM		Mean % survival ± SEM[a]		Mean total adults ± SEM	
	Laboratory	Wild-type	Laboratory	Wild-type	Laboratory	Wild-type
Wheat bran	(94.0)[b]	45.0 ± 0.91ab	95.3 ± 1.25a	97.3 ± 4.13a	272.0 ± 3.58a*	191.7 ± 10.0a*
Pistachios	91.7 ± 0.25c*	43.7 ± 1.80b*	91.7 ± 1.31ab*	84.3 ± 0.85b*	254.5 ± 3.92b*	158.3 ± 6.88b*
Walnuts	94.7 ± 1.03b*	44.3 ± 1.38b*	86.5 ± 1.66bc	82.5 ± 0.50b	254.0 ± 3.53b*	152.5 ± 2.78b*
Almonds	94.7 ± 0.48b*	43.0 ± 1.87b*	81.3 ± 2.43c	76.5 ± 0.87b	227.0 ± 5.12c*	142.3 ± 0.63b*
Raisins	97.3 ± 0.25a*	53.0 ± 2.83a*	6.5 ± 0.29d	7.3 ± 0.85c	18.3 ± 0.85d	15.3 ± 1.80c
Prunes	94.0 ± 0.41bc*	44.7 ± 1.49b*	0.7 ± 0.48d*	11.0 ± 1.68c*	2.5 ± 1.32e*	20.7 ± 2.84c*

Means within columns followed by the same letter are not significantly different ($P \geq 0.05$ level; Tukey's studentized range test [SAS Institute 1987]). *, Significant difference between means of isolates ($P \leq 0.05$ level, t-test [SAS Institute 1987]).

[a] Percentage of survival, emerging adults/hatched eggs.

[b] Value calculated by averaging overall percentage of egg hatch, not used in analysis.

Analysis of variance for egg hatch showed significance ($P < 0.05$) for isolates ($F = 4{,}029.11$; df = 1, 47; $P = 0.0001$) and for the diets ($F = 7.56$; df = 5, 47; $P = 0.0001$), but no interaction between isolates and diets ($F = 1.87$, df = 5, 47; $P = 0.12$). Egg hatch for the wild-type isolate was much lower than for the laboratory isolate (t = 15.58–31.82, df = 6, $P = 0.0001$). For both isolates, egg hatch was highest on raisins.

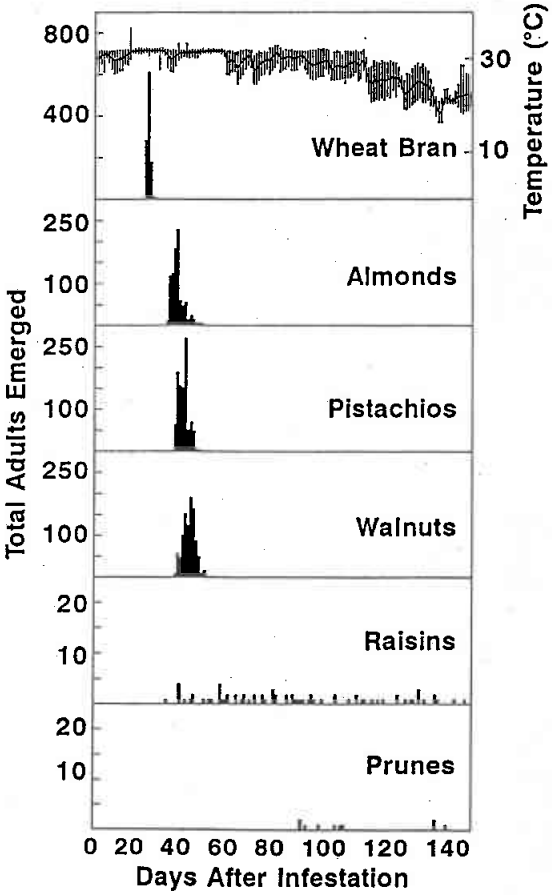

Fig. 3. Average daily temperature and adult emergence of laboratory isolate from different diets.

Survival from neonate to adult was similar for both isolates, and greatly affected by diet. ANOVA resulted in significance ($P < 0.05$) for the diets ($F = 1{,}221.54$; df = 5, 47; $P = 0.0001$) but no significance for isolates ($F = 0.31$; df = 1, 47; $P = 0.58$). Interaction between isolates and diets was also significant ($F = 7.03$; df = 5, 47; $P = 0.0001$). When the diets within each isolate were analyzed, mean separation showed survival to be best on wheat bran and worst on dried fruits. Survival on nut diets differed with the isolates; the wild-type isolate survived equally on nuts, but the laboratory isolate survived better on pistachios than on walnuts. When t-tests were performed to compare isolates on each diet, the survival of the laboratory isolate was higher than the wild-type isolate on pistachios ($t = 4.78$, df = 6, $P = 0.005$), but lower than the wild-type isolate on prunes ($t = -5.86$, df = 6, $P = 0.007$). Survival was similar on all other diets (t = −0.83–2.31, df = 6, $P > 0.05$).

Analysis of variance for total adults emerging showed significance ($P < 0.05$) for isolates ($F = 511.05$; df = 1, 47; $P = 0.0001$), diets ($F = 1{,}025.33$; df = 5, 47; $P = 0.0001$) and interaction between isolates and diets ($F = 68.08$; df = 5, 47; $P = 0.0001$). With the exception of the dried fruits, total adults were higher in the laboratory isolate (t = 7.55–22.55, df = 6, $P < 0.05$). Total adults of the wild-type isolate were higher than the laboratory isolate on prunes ($t = -5.83$, df = 6, $P = 0.001$), and similar on raisins ($t = 1.51$, df = 6, $P = 0.20$). When the diets within each isolate were analyzed, total adults were highest on wheat bran, and lowest on the dried fruits. Total wild-type adult numbers were similar on all three nuts, but walnuts produced significantly fewer laboratory adults. Wild-type adult numbers were similar in the dried fruits, but prunes produced significantly fewer laboratory adults than raisins.

The pattern of adult emergence from the different diets is similar for the two isolates (Figs. 3 and 4). Emergence over time from the wheat bran diet is compressed, with numbers rapidly peaking and then quickly dropping off. All emergence from wheat bran diet occurred within a 10-d period. The pattern of emergence from the three nut diets is similar, but emergence occurred during 20 d.

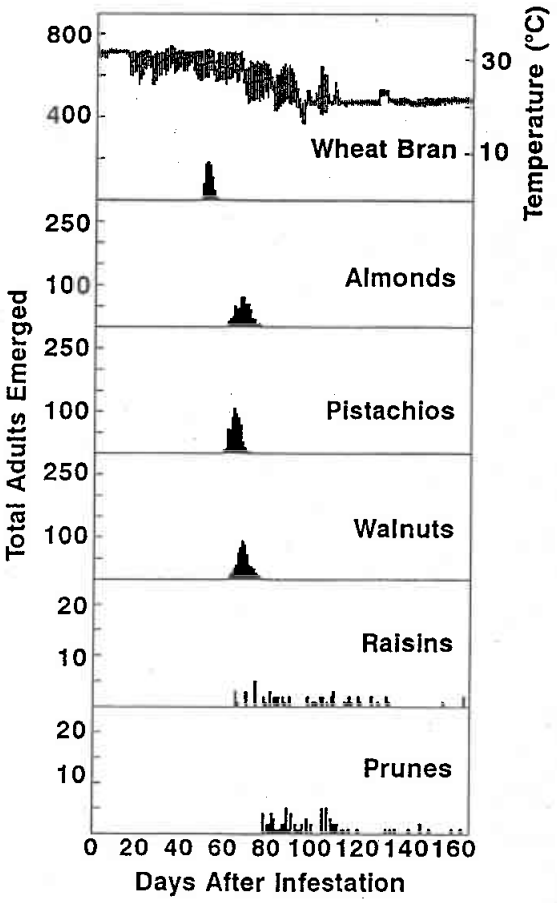

Fig. 4. Average daily temperature and adult emergence of wild-type isolate from different diets.

Emergence from the dried fruits is spread out over a long period, with no obvious peak emergence. Emergence of the laboratory isolate from all diets except prunes occurred earlier than the wild-type isolate.

Degree-days for the isolates on the diets were calculated using 14°C as a lower threshold (Table 2). Analysis of the wheat bran and nut diets was done separately from the dried fruits because of wide differences in variances. ANOVA for degree-days for the wheat bran and nut diets showed significance ($P < 0.05$) for isolates ($F = 54{,}951.61$; df = 1, 31; $P = 0.0001$), diets ($F = 2{,}996.66$; df = 3, 31; $P = 0.0001$) and the interaction between isolates and diet ($F = 73.03$; df = 3, 31; $P = 0.0001$). When t-tests were used to compare the isolates on each diet, degree-days for the laboratory isolate was always significantly lower than the wild-type isolate ($t = -186.39$ to -82.54, df = 6, $P = 0.0001$). Mean separation of the diets for each isolate showed that both isolates developed fastest on wheat bran and slowest on walnuts. The laboratory isolate developed faster on almonds than pistachios, but this was reversed for the wild-type isolate.

Table 2. Degree-days for egg to adult development of two Indianmeal moth isolates on different diets

Diet	Mean degree-days ± SEM	
	Laboratory	Wild-type
Wheat bran and nut diets		
Wheat bran	345 ± 2.32a*	844 ± 2.25a*
Pistachios	574 ± 2.05c*	1,036 ± 1.39b*
Walnuts	613 ± 2.91d*	1,092 ± 1.72d*
Almonds	536 ± 6.53b*	1,082 ± 1.06c*
Dried fruit diets		
Raisins	1,241 ± 112.43a	1,382 ± 32.35a
Prunes	1,616 ± 224.55a	1,383 ± 13.66a

Means within columns followed by the same letter are not significantly different ($P \geq 0.05$ level; Tukey's studentized range test [SAS Institute 1987]). Wheat bran and nut diets were analyzed separately from dried fruit diets. *, Significant difference between means of isolates ($P \leq 0.05$ level, t-test [SAS Institute 1987].

ANOVA for the dried fruits showed no significant difference between isolates, diets, or their interaction ($P > 0.05$). Degree-days for dried fruits was much higher than for wheat bran and nut diets.

Effect of Diet on Reproduction. The effect of the different diets on reproduction is given in Table 3. Only those pairs that produced progeny were included in the analysis. Only 7 out of 15 pairs of the laboratory isolate reared on wheat bran produced progeny; all other isolates and diets had at least 11 out of 15 pairs with progeny, except for the laboratory isolate on prunes, which had 3 out of 6 pairs with progeny. ANOVA for progeny per female showed significance ($P < 0.05$) for diets ($F = 7.7$; df = 5, 141; $P = 0.0001$) and no significance for isolates ($F = 0.09$; df = 1, 141; $P = 0.77$) or interaction between isolate and diet ($F = 1.4$; df = 5, 141; $P = 0.23$). Mean separation of diets showed that the laboratory isolate reared on pistachios produced significantly more progeny than those on almonds, raisins, or prunes. The wild-type isolate reared on almonds, pistachios, and wheat bran produced significantly more progeny than those on prunes. When t-tests were used to compare the isolates on each diet, the laboratory isolate reared on almonds was found to produce significantly fewer progeny ($t = -2.54$, df = 22, $P = 0.017$) than the wild-type. Progeny numbers for both isolates were similar ($t = -0.37$–1.93, df = 19–28, $P > 0.05$) from all other diets.

Analysis of variance for progeny male/female sex ratios showed significance ($P < 0.05$) for isolates ($F = 11.32$; df = 1, 141; $P = 0.001$) but no significance for diet ($F = 1.31$; df = 5, 141; $P = 0.27$) or the interaction between isolates and diets ($F = 0.54$; df = 5, 141; $P = 0.75$). When t-tests were used to compare the isolates on each diet, progeny sex ratios of the wild-type isolate on the wheat bran and nut diets were all significantly higher than those of the laboratory isolate ($t = -3.30$ to -1.73; df = 19–28; $P < 0.1$). Progeny ratios on the dried fruits were similar ($t = -0.18$, df = 12–24, $P > 0.1$).

Table 3. Progeny produced by two Indianmeal moth isolates reared on different diets

Diet	Laboratory			Wild-type		
	n	Mean progeny/ ♀ ± SEM	♂/♀ ± SEM	*n*	Mean progeny/ ♀ ± SEM	♂/♀ ± SEM
Wheat bran	7	66.0 ± 5.8ab	0.79 ± 0.07**	14	68.5 ± 3.5a	0.96 ± 0.06**
Pistachios	12	81.7 ± 5.4a	0.59 ± 0.05**	15	70.3 ± 3.1a	0.84 ± 0.05**
Walnuts	15	65.7 ± 3.2ab	0.64 ± 0.06**	15	65.0 ± 5.5ab	0.84 ± 0.09**
Almonds	13	57.4 ± 4.0b*	0.77 ± 0.07**	11	73.1 ± 4.7a*	0.99 ± 0.11**
Raisins	15	48.2 ± 5.5b	0.78 ± 0.09	11	50.4 ± 7.3ab	0.80 ± 0.08
Prunes	3	44.3 ± 13.0b	0.78 ± 0.17	11	45.3 ± 8.5b	0.83 ± 0.15

Means within columns followed by the same letter are not significantly different ($P \geq 0.05$ level; Tukey's studentized range test [SAS Institute 1987]). *, Significant difference between means of isolates ($P \leq 0.05$ level, *t*-test [SAS Institute 1987]); **, significant difference between means of isolates ($P \leq 0.1$ level, *t*-test [SAS Institute 1987]).

Discussion

Indianmeal moth is the storage pest of most concern to processors of raisins, prunes, almonds, pistachios, and walnuts. The results of the current study, however, show that developmental rates and survival of Indianmeal moth were much lower on dried fruits than on nuts. The reason for this is unclear. Humidity and moisture content of diets have been found to affect both survival and development of Indianmeal moth and related pyralids. Abdel-Rahman et al. (1968) showed that higher moisture contents of corn varieties were often more suitable for development of Indianmeal moth. Similar results were found by Warren (1956) for Angoumois grain moth, *Sitotroga cerealella* (Olivier). Mbata & Osuji (1983) showed that relative humidities of 70–80% were best for Indianmeal moth development on peanuts, and that 60% RH slowed development and decreased adult weight. Johnson et al. (1992) found a positive correlation ($R > 0.97$) between moisture levels of diets and developmental rates and survival.

However, moisture content for dried fruits is typically much higher than that of nuts. In the current study, moisture contents of the nuts was only one-third that of the dried fruit. Savov (1973a) also found that Indianmeal moth reared on walnuts and almonds had shorter developmental times than those reared on dried fruits. Even when comparing similar diets, moisture content may be secondary; development of both Indianmeal moth and Angoumois grain moth varied considerably between different corn cultivars of identical moisture contents (Warren 1956, Abdel-Rahman et al. 1968). Swatonek (1973) found a negative correlation between larval developmental rates and mortality of Indianmeal moth reared on paprika cultivars with different capsaicin contents. Obviously, moisture content cannot be the only determining factor, especially when comparing widely different diets.

Overall survival on the wheat bran and nut diets, when measured as the number of emerging adults, was much higher for the laboratory isolate than the wild-type isolate. This was caused by the reduced egg hatch of the wild-type isolate; postembryonic survival of the two isolates on wheat bran and nut diets was similar. The reason for the poor hatch of the wild-type isolate is unknown, but may have been the result of undetected disease or lower mating sucess in the recently isolated stock. Postembryonic survival of both isolates on dried fruit was very poor (<12%), but survival of the wild-type isolate on prunes was significantly higher than the laboratory isolate. Because the wild-type isolate was obtained from culled figs, it may have been preconditioned for improved survival on prunes.

In an earlier study (Johnson et al. 1992), survival of Indianmeal moth reared on ground walnuts was significantly less than those reared on ground almonds or ground pistachios. At 35°C, egg hatch was reduced and no adults emerged from walnuts. In the current study, where whole walnut halves were used instead of ground walnuts, egg hatch and survival of both isolates on walnuts was similar to or higher than almonds and pistachios. Oxidative rancidity in walnuts can be induced by storage at high temperatures (>35°C) and by grinding (Musco & Cruess 1954). Possible end products of rancidification include volatile aldehydes and ketones which may be toxic to insects. Thus, the results reported in Johnson et al. (1992) for walnuts was possibly caused by rancidity caused by grinding.

In the same study (Johnson et al. 1992), we estimated lower developmental thresholds to be 16.6, 17.5, 17.1, and 18.0°C for Indianmeal moth egg to adult emergence on wheat bran diet, ground almonds, ground pistachios, and ground walnuts, respectively. We felt that these temperatures were too high to be accurate. Savov (1973b) determined the lower developmental temperature threshold for Indianmeal moth to be much lower (13.5°C). Because of temperature-dependent diapause induction in the larval stage (Tzanakakis 1959, Bell 1976), we were limited to temperatures of 22°C or above. In addition, diet had an effect on larval development, yielding a different threshold for each diet. The current study avoided these problems by determining thresholds for eggs and pupae, stages unaffected by diapause or diet.

Developmental rates for eggs and pupae of both isolates were nearly identical, but degree-days ac-

cumulated for egg to adult emergence of the laboratory isolate on the wheat bran and nut diets were much lower than for the wild-type isolate. Continuous culturing of the laboratory isolate may have selected for a faster larval developmental rate. Accumulated degree-days for both isolates on dried fruit were statistically similar; again, this may be because the wild-type isolate was preconditioned for survival on dried fruit. These results show that wild-type isolates are essential for development of degree-day information.

Simmons & Nelson (1975) gave the average number of eggs per female produced by Indianmeal moth on dried fruit to be 170. The average number of adult progeny produced per female for Indianmeal moth reared on wheat bran diet and ground nuts ranged from 258.5 to 339.1 (Johnson et al. 1992). In the current study, average adult progeny numbers for both isolates on the different diets were much lower, ranging from 44.3 to 81.7. To maintain uniformity in the test, a single batch of wheat bran diet was frozen and used for all progeny determinations, a practice often used for the maintenance of stock moth cultures without adverse effects. Freezing may have altered the diet and caused the reduced progeny numbers. The low progeny numbers obtained in our study should not be used to infer that Indianmeal moth is not a serious pest on these products.

The determination of developmental thresholds for eggs and pupae allows the use of a single lower threshold in all models. Different degree-days for each commodity, however, will still be necessary. A variety of nuts and dried fruits, all susceptible to infestation by Indianmeal moth, are produced and processed in the California Central Valley, sometimes in the same packing plant. Not all product within a single packing plant is stored under the same temperature and humidity conditions. These factors add to the complexity of any proposed model. Despite these difficulties, information on Indianmeal moth developmental rates should eventually lead to more efficient pest management.

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